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DEMONSTRATIVE EARLY WARNING SYSTEM IN THE EASTERN PYRENEES

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SUMMARY

The existing seismic information systems at the present time in Europe are limited in the amount of provided useful information. With the purpose of improving this situation a demonstrative Regional Automatic Seismic Damage Information system (ISARD project) has been developed on the Eastern Pyrenees (some Provinces in Spain, a French Department and Andorra). A real time system based on a VSAT seismic network has been developed first in Catalonia and is planned to be operational in an extended region at the end of 2006, with 3 new accelerometric stations in France, 1 in Andorra and a total of 19 seismic stations for the seismic network. This project is financially supported by FEDER, the French Environment Ministry and the Catalan Public Works Department. The system can generate automatically a few minutes after the earthquake an informative note with the estimation of the possible damages for Civil Defence crisis managers. The scenarios are defined following vulnerability assessment methodologies applied to the municipality scale using GIS techniques. This automatic seismic information system can contribute to enhance the management of the crisis and sharing of each country's first-aid organizations.

1. INTRODUCTION

Located on the border between Spain and France, the Pyrenees region is one of the most active seismic zones of the two countries. Its historical seismicity and recent tectonics data indicate an important level of seismic hazard. Earthquakes with magnitudes between 4.5 and 6.5 have caused damages in the past. Since 2004, the ISARD project: Regional Automatic Seismic Damage Information system has been studying both the seismic hazard and vulnerability of this region in order to develop a common scheme for generating seismic risk scenarios that surpasses the countries' borders and provide preventive and operational information on the seismic risk to the local first-aid and crisis management organizations (www.isard.net). One of the main objectives of the ISARD project is to allow the fast diffusion to the crisis management agencies of an informative note with real time earthquake information including an estimate of the damage that may be caused by the earthquake.

Right now, a real time system is functioning in Catalonia to send an SMS message informing of the localization and magnitude of the earthquake event. The system being implemented in Eastern Pyrenees will allow us to improve the real time system, with the possibility of fast diffusion to Civil Defence agencies of an informative note with the estimation of the possible damages at both sides of the Eastern Pyrenees border, within a few minutes after the earthquake

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2. VSAT SEISMIC NETWORK

A real time system based on a VSAT seismic network has been developed first in Catalonia [Goula et al., 2001] and it is planned to be operational at the end of 2006 in an extended region, with 3 new accelerometric stations in France, 1 in Andorra and a total of 19 seismic stations for the seismic network.

The stations are based on VSAT platforms sending continuous almost real time seismic data via satellite to the Hub at the processing centre of the Institut Cartogràfic de Catalunya (ICC) in Barcelona (Spain) and from there to the Bureau de Recherches Géologiques et Minières (BRGM) at Orleans (France), using a securised Virtual Private Network. Data are continuously stored and processed with an automatic location system (DAS) at two Seismic Reception Data Centre in Barcelona and Orleans (France).

At the present time (April, 2006), 10 field stations are operative, with STS-2 and Guralp CMG-3T sensors together with the reception and processing centre (See Figure 1). Five more stations (#11 to 15 in Figure 1) are under construction. One other station is planned in Andorra (#16 in Figure 1) and three more stations are under construction (# 17 to 19 in Figure 1), in the South of France. They will be equipped with Kinemetrics epi-sensors. All the stations will be operational at the end of 2006.

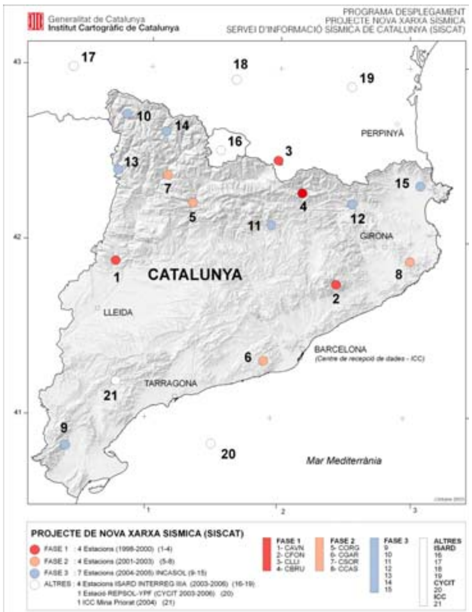

Figure 1: Map of situation of BroadBand stations of the VSAT Network

Figure 2: View of VSAT - CASSA Station

A view of CASSA Station (# 8 in Figure 1) with a borehole sensor in the house, the solar cells and the VSAT antenna is shown in Figure 2. All stations are provided with high performance electrical and environmental protections.

3. DETECTION AUTOMATIC SYSTEM (DAS)

DAS has been created from Automatic Earthworm (EW) modules [USGS, 2005] adapted to give solutions to the main ISARD requirements and VSAT network conditions, i.e. real time processing of waveforms coming from the acquisition software of Nanometrics (NAQS); taking into account functionalities of trigger detection; their coherent association; hypocenter location and database archiving [Romeu et al., 2006]. A simplified diagram of the proposed architecture is shown in Figure 3.

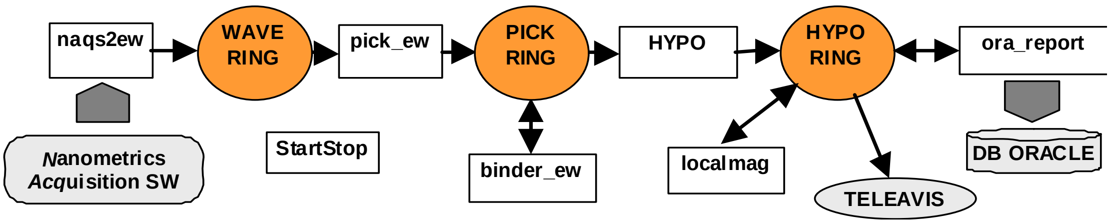

Figure 3: Simplified diagram of the Automatic Earthworm modules installed at ICC

The configuration of the following EW modules has been performed:

i) Pick_ew. The different parameters of the STA/LTA algorithm [Allen, 1978] were adapted to each station conditions: noise, type of sensor, etc., in order to produce triggers, even, for small magnitude events, but avoiding spurious triggers.

ii) Binder_ew. This module identifies seismic events in a coherent and rapid way, from the triggers declared as first arrivals (P phase). The algorithm is based on a geometrical coincidence of time differences of the triggers (hyperboloids crossing). In the case that more than 4 triggers are coherent a new event is declared and a preliminary hypocenter is retained. This hypocenter is used as a first solution for an iterative process of location done by HYPOINVERSE-2000 [Klein, 2002]. Finally the module may decide if the event is valuable or not, due to the number of phases, RMS value, etc.

iii) Localmag. This module uses the travel times of different picked phases to estimate the length of the record to be retained for each horizontal component of all the stations. From the records retained, the algorithm filters the offset and proceeds to the instrumental correction before to obtain a Wood-Anderson simulated record. The final Ml is estimated from the average of the Magnitudes computed in all the selected horizontal components.

The results obtained during the test period seem to be satisfactory, i.e. a very few spurious events (noise or teleseisms) are retained; the quasi totality of local events with M>1.3 is detected and the locations are very precise compared to manual locations.

4. GENERATION OF AUTOMATIC DAMAGE SCENARIOS (TELEAVIS)

TELEAVIS is an application designed for the automatic generation of reports from the hypocentre data of the earthquakes detected by DAS and for its transmission by fax, SMS, ftp and electronic mail. From the data received from DAS, TELEAVIS develops an epicentral location map with planimetry of 1:250000 and calculates the damage scenario using the methodology proposed by Susagna et al. (2006) and Roca et al. (2006). The validity of the method is limited to earthquakes with magnitudes lower than 6.5. The methodology consists of three steps:

i) Estimation of epicentral intensity. Once the epicentre depth and magnitude of the earthquake has been determined by DAS, it is possible to estimate the epicentral intensity from a correlation between magnitudes and intensities felt by the population.

ii) Intensity attributed to each municipality. A relationship for the attenuation of intensity with distance for Catalonia has been fitted to the intensity data available in a database of felt earthquakes. In this first version, circular isoseismal are considered. The hypothesis of a punctual source limits the validity of the method to earthquakes with magnitudes not greater than 6.5, for which the size of the source needs to be considered.

iii) Estimation of building damage, assessment of the human casualties and evaluation of economic losses. In the case of intensities are greater than 5 (EMS98) these calculations are carried out following the methodology developed by Susagna et al. (2006) and Roca et al. (2006). The number of uninhabitable buildings, the total of homeless, and the total of affected people are also obtained. Data on building occupancy (inhabitants / building) for each municipality and average surface of houses are used. The number of victims can be estimated using damage data from past earthquakes [Coburn and Spence, 1992; ATC-13, 1985] considering the results of damaged buildings that have been previously obtained together with data of the population census.

Two different methods are used to compute automatic damage scenario, in function of data availability:

-Level 0 method is based on the following hypothesis:

a. the unit of work is the total area of the municipality
b. soil conditions are not considered
c. EMS'98 scale is used to define vulnerability classes, and Damage Probability Matrices.

-Level 1 method:

a. the units of work are differentiated polygons in each municipality,
b. soil effects are considered,
c. typologies are defined by structural and constructive criteria and vulnerability indexes and functions are used for each typology following RISK-UE methodology [Mouroux and Lebrun, 2006].

4.1 Level 0 Eastern Pyrenees automatic scenario

The Level 0 automatic scenario has been applied to the municipalities of Catalonia, two municipalities of Andorra and the Département des Pyrénées Orientales of France. The classification of the dwelling buildings of the study region, according to the defined classes of vulnerability in the EMS-98, has been elaborated from data from the buildings census made in 1990 by the Institute of Statistics of Catalonia (IEC) and by the BRGM from IGN/INSEE/field investigation for the French part. For Andorra, the data was extracted from the Municipal Urbanism and Organization plans (POUP) and has been complemented with aerial photos and field surveys. The available information is the age, the height and the geographic location of the buildings.

The vulnerability assessment is based on the classification of the building stock of each municipality according to the EMS-98 [Grünthal, 1998] vulnerability classes using the methodology developed by Chávez (1998) and exposed by Roca et al. (2006). Figure 4 shows the vulnerability classes assigned by the EMS-98 to common structures of masonry, reinforced concrete, steel and wood. Chávez (1998) established the distribution of the vulnerability classes according to the age, height and location of the building stock. To obtain the number of buildings in each vulnerability class, the age and height distribution must be known for both the urban and rural areas of the municipality. The vulnerability classes distribution, also shown in Figure 4, was defined based on the expert judgment of architects who knew very well the construction history of the Catalonian region in Spain.

The age and the height are clearly associated to the seismic vulnerability of the buildings. The age not only has importance by its effect on the process of loss of the resistance of the building but is indicative of constructive techniques, variable throughout time. According to information collected by specialists it has been possible to make three groups of buildings according to the period of construction: previous to 1950, between 1950 and 1970 and after 1970. On the other hand, the height influences the response of the buildings to a seismic action.

	Vulnerability Classes Percentages by Chavez (1998)					
	Until 1950		1951–1970		After 1970	
Levels	Urban	Rural	Center	Dissem	Center	Dissem
< 5	20A 80B	30A 70B	5A 50B 45C	15A 70B 15C	85C 15D	5A 20B 65C 10D
= 5	20A 80B	40A 60B	10A 60B 30C	20A 70B 10C	5A 20B 65C 10D	10A 30B 55C 5D
> 5	40A 60B	60A 40B	15A 70B 15C	30A 65B 5D	8A 27B 60C 5D	15A 45B 40C

Figure 4: Distribution of vulnerability classes according to Chávez (1998)

The estimation of the damage has been made by means of probability damages matrices that have been determined for the classes of vulnerability A, B, C, D, E and F, the degrees of damages of 0 (no damage) to 5 (total collapse) and the degrees of intensity (VI to X) of the EMS-98 scale [Chávez, 1998; Chávez et al., 1998]. An example for intensity VIII is presented in Figure 5.

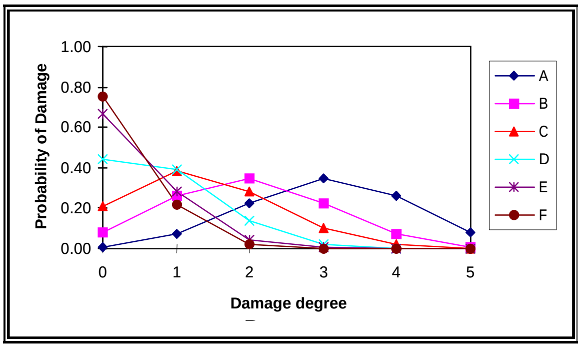

Figure 5: Probability damages matrix for intensity VIII

As a result of the evaluation of the physical damage, the number of buildings of each municipality distributed according to the different damage degrees is obtained. From the damage experienced by the buildings has been elaborated an estimation of how many of them could stay in uninhabitable conditions, considering those that undergo the degrees of damages 4 and 5 to be in this state as well as 50% of those that experience damage 3. These results are of maximum importance for the evaluation of the possible number of homeless after occurrence of the earthquake.

The automatic report generated by TELEAVIS, using Level 0 method consists of a map of location with the planimetry at scale 1:250.000, maps with different parameters characterizing damage and a list of municipalities with the relation of damages. The scenario concerns all the municipalities of Catalonia (Spain), Département des Pyrénées Orientales (France) and two municipalities of Andorra.

An example of the estimated number of homeless is shown on Figure 6 for a hypothetical earthquake of M5 occurring in the Cerdanya region.

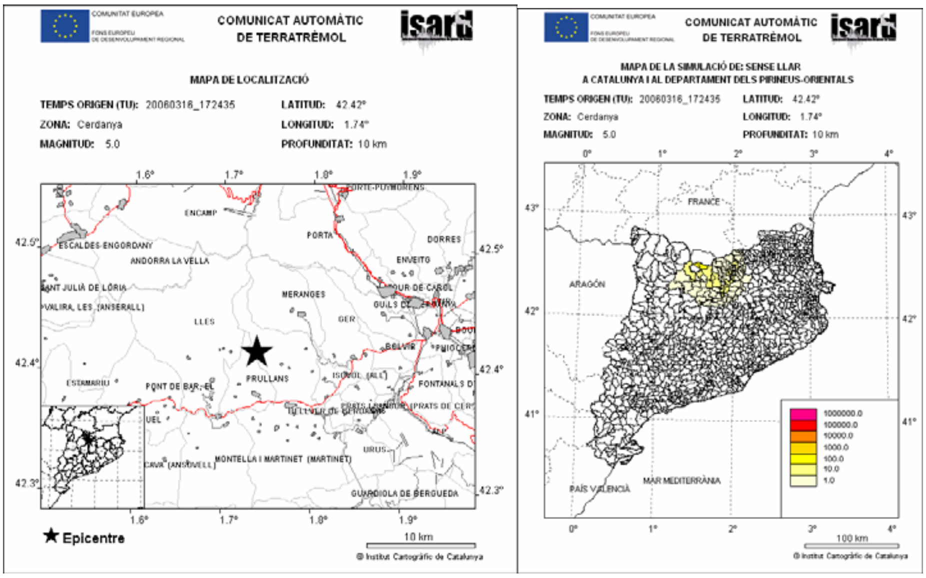

Figure 6: Location of a hypothetical M5 earthquake in Cerdanya region and number of homeless estimated in the study region: Catalonia, Département des Pyrénées Orientales and 2 municipalities of Andorra

4.2 Level 1 automatic scenario

The Level 1 damage assessment is being applied to a pilot zone within the study region that includes both the French and Spanish Cerdanya, and two municipalities of Andorra, but later the methodology will be extended to a wider region. This methodology is based on the vulnerability index method [Corsanego and Petrini, 1994; Bernardini, 2000; Giovinazzi and Lagomarsino, 2004] in which the building stock is classified according to structural typologies characterized by a vulnerability index. These vulnerability indexes allow calculating the possible damages due to a certain earthquake by means of a vulnerability function as can be seen in Figure 7. The vulnerability function recommended within the RISK-UE for dwelling buildings was developed by Sandi and Floricel (1995) and is shown in Equation 1.

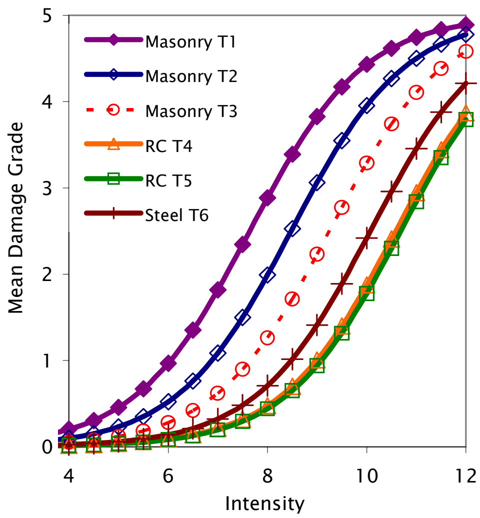

Figure 7: Mean vulnerability curves for the principal typologies in the pilot region

$$\mu_d = 2.5\left[1+\tanh\left(\frac{I+6.25V_I-13.1}{3.0}\right)\right] \qquad (1)$$

The structural typologies defined within the RISK-UE project [Mouroux and Lebrun, 2006] were used to construct building typology matrix for the pilot zone. Figure 8 shows the structural typologies representative of the pilot zone along with its correspondence to RISK-UE typologies and the mean values of vulnerability indexes recommended by Lagomarsino et al. (2002). Vulnerability index modifiers are also available in order to enhance the definition of the vulnerability of the building stock by increasing or decreasing the vulnerability as function of certain structural parameters. Milutinovic and Trendafiloski (2003) summarize the vulnerability index modifiers proposed within the RISK-UE project of which only those associated to the height, age, soft story condition and design code level will be applied in the pilot zone.

Typology		*Description*	*Risk-UE*	*Mean Vuln. Index*
Unreinforced Masonry	*T1*	Stone masonry bearing walls made of rubble stone or fieldstone	*M1.1*	*0.873*
	T2	Unreinforced masonry bearing walls with wooden slabs	*M3.1*	*0.740*
	T3	Unreinforced masonry bearing walls with concrete slabs	*M3.4*	*0.616*
Reinforced Concrete	*T4*	Reinforced concrete frames with unreinforced masonry infill walls	*RC3.1*	*0.402*
	T5	Reinforced concrete shear walls	*RC2*	*0.386*
Steel	*T6*	Steel frame with unreinforced masonry infill walls	*S3*	*0.484*
Wood + Steel	*T7*	Wood structure supported on Masonry	*N/A*	*0.500*
Adobe	*T8*	Adobe structures	*M2*	*0.840*

Figure 8: Principal structural typologies for the pilot zone with its vulnerability indexes from RISK-UE

A distribution of typologies has been determined for the municipalities of French and Spanish Cerdanya, according to the expert judgement done by local and the ISARD project specialists of CSTB, BRGM and ICC teams [Roussillon et al., 2006]. Figure 9 shows the polygons for the population entities drawn from INE data in Spanish Cerdanya and from INSEE data from French Cerdanya. The typologies distribution allows obtaining a distribution of the vulnerability index for each population polygon that will be used for calculating its expected damages. The vulnerability index distribution is then combined with the intensity with soils effects that affects each polygon using the vulnerability function in order to compute the distribution of damages expected in each polygon.

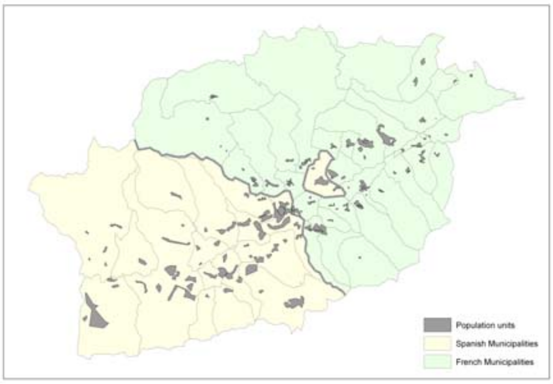

Figure 9: Polygons for the population entities for the pilot zone

Soil effects are considered in order to modify the mean intensity in each municipality and obtain the intensity with soils effects that affect each of the population polygons. A new methodology has been developed in the ISARD project, presented in this same issue by Macau et al. (2006), in which the Intensity increments are estimated taking into account the Arias Intensity computed from records obtained at the top of soil columns characterized using both geological and geophysical parameters. Figure 10 presents the seismic microzonation map for the Cerdanya region proposed by Macau et al. (2006).

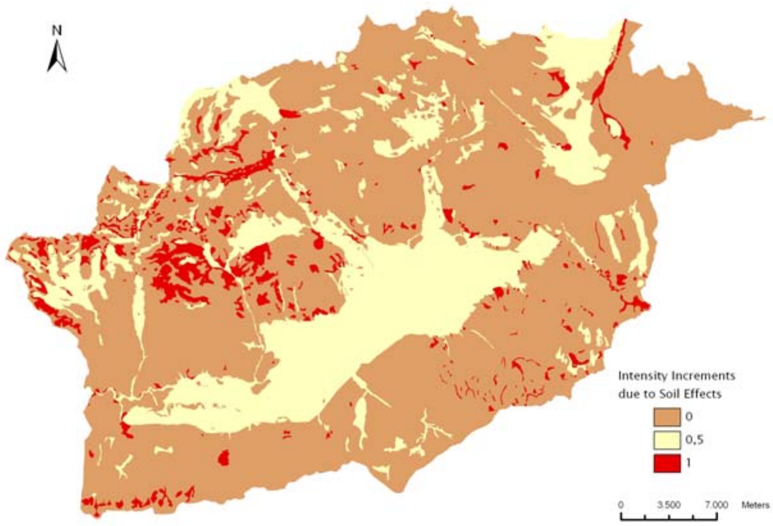

Figure 10: Map of seismic microzonation of the Cerdanya, proposed by Macau et al. (2006)

A new version of the TELEAVIS code, currently being developed, will compute the damage scenarios considering soil effects for each municipality by adding the damage and losses contributions of each urban polygon. This new version will also contain the same maps and tables shown before, plus Level 1 damage scenarios for the municipalities of both French and Spanish Cerdanya, Andorra and the cities of Girone and Perpignan. A preliminary shake map will also be produced with the recorded PGA and PGV values of horizontal records on the VSAT network.

5. CONCLUSIONS

A demonstrative Regional Automatic Seismic Damage Information system (ISARD project) has been developed on the Eastern Pyrenees (some Provinces in Spain, a French Department and Andorra), with a real time system based on a VSAT seismic network with 19 seismic stations placed in Catalonia (Spain), South of France and Andorra planned to be operational at the end of 2006. A Detection Automatic System (DAS) has been developed from Automatic Earthworm (EW) modules to give solutions to the main ISARD requirements and VSAT network conditions.

An application (TELEAVIS) has been designed for the automatic generation of reports from the hypocentre data of the earthquakes detected by DAS and for its transmission by fax, SMS, ftp and electronic mail. From the data received from DAS, TELEAVIS currently develops an epicentral location map with planimetry of 1:250000 plus maps and tables with Level 0 damage scenario for municipalities of Catalonia, French Département des Pyrénées Orientales and Andorra. More precise scenarios are under development using the Level 1 methodology for municipalities of French and Spanish Cerdanya, Andorra and the cities of Girone and Perpignan. The automatic generation of a map with the PGA and PGV values recorded by VSAT stations is also being developed.

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